

1 METHOD AND APPARATUS FOR FILLING VIAS

2 FIELD OF THE INVENTION

3 This invention is directed to a process and apparatus,
4 and in particular tooling, for enabling the creation of
5 filled, and preferably conductive, vias and
6 through-vias in a semiconductor substrate. More
7 particularly, it is directed to a process and apparatus
8 for enabling the filling of such vias.

9 BACKGROUND OF THE INVENTION

10 There are many advantages to using silicon as a
11 substrate for electronic packaging, rather than
12 traditional ceramic and organic laminate packaging.
13 Some of the key features of the silicon carrier
14 include: the ability to create high performance wiring
15 and joining at much finer pitch than typical packaging,
16 the ability to join heterogeneous technologies or
17 different generation technologies for high speed
18 applications, the ability to integrate passives, MEMs
19 or optical fibers, the ability to add silicon
20 functionality to the carrier package in addition to
21 wiring, the ability to dramatically increase the I/O
22 density, and for many applications, the ability to
23 reduce overall system cost when compared to other
24 system on package (SOP) approaches which do not use Si
25 as the carrier.

1 Elements and structures of semiconductor packages have
2 been described in United States Patent No. 5,998,292 to
3 Black et al. and United States Patent No. 6,593,644 to
4 Chiu et al. In order to attain the advantages outlined
5 above several key steps are necessary, as shown in
6 Figs. 1A to 1F. As illustrated in Fig. 1A, first,
7 deep blind vias 10 (several hundred microns in depth) are
8 etched into a silicon wafer 12, and sidewall insulation
9 14 is deposited. As shown in Fig. 1B, vias 10 must be
10 completely filled with a conductor 16. Once the vias
11 are filled, as shown in Fig. 1C, standard BEOL wiring
12 levels 18 can be built on top of the silicon wafer 12,
13 and the whole wafer can be thinned by backside grinding
14 to expose the via conductors on the backside, as shown
15 in Fig. 1D. As shown in Fig. 1E, solder connections,
16 such as C4 solder balls 20 may then be built on the
17 carrier back, and chips 22 may be joined to the front,
18 by any one of a number of conventional techniques such
19 as flip chip bonding as illustrated in Fig. 1F,
20 completing the high performance silicon carrier package
21 24.

22 At this point there are several options, one of which
23 is illustrated in Fig. 2, where the high performance
24 silicon carrier package 24 is joined to a ceramic
25 module 26 by means of solder balls 20, and then to a PC
26 board 28 by means of, for example, additional C4 solder
27 balls 30.

1 Of all the key technology elements described above,
2 that which is most problematic is the filling of high
3 aspect ratio blind vias with conductor. Filling with
4 common metals by PVD or CVD methods is impractical,
5 while plating becomes extremely difficult due to the
6 tendency for the plated side walls to "breadloaf" at
7 the top, cutting off the via from further filling, and
8 trapping plating solution in a central void. Even if
9 these or other methods of solid metal filling, such as
10 filling with molten metal, could be made to work,
11 typical metals have a large coefficient of thermal
12 expansion (CTE) mismatch with silicon. There are three
13 potential problems associated with large CTE mismatches
14 between the vias and the silicon substrate:
15 delamination at the via side walls; cracking of the
16 silicon substrate between vias; and piston-like rupture
17 of any overlying or underlying structures or thin films
18 in contact with the top/bottom surfaces of the vias.
19 Accordingly it is advantageous to use a material which
20 is simultaneously conductive with a good CTE match to
21 silicon.

22 One such material which has been used by International
23 Business Machines Corporation in the production of
24 glass ceramic multi-chip modules (MCM) is a paste
25 containing a mixture of copper and glass particles
26 suspended in a mixture of organic solvents and binders.
27 Such pastes are typically applied to a patterned
28 ceramic greensheet by a screen printing method, after
29 which the sheets are stacked and sintered at high

1 temperature, during which the organic components are
2 burned off, and the glass and Cu components coalesce to
3 form conductive lines and vias.

4 Recently, in "Filling the Via Hole of IC by VPES
5 (Vacuum Printing Encapsulation Systems) for stacked
6 chip (3D packaging)", Atsushi Okuno and Noriko Fujita,
7 2002 Electronic Components and Technology Conference
8 have described the adaptation of a vacuum printing
9 encapsulation system (VPES) for filling blind vias with
10 conductive paste. The VPES method was originally used
11 to deliver plastic resin in the manufacture of ball
12 grid array (BGA) and CSP packaging, wafer level CSP
13 packaging, transparent resin encapsulating for light
14 emitting diode (LED) displays, flip-chip under-filling,
15 and other processes. For BGA or CSP packaging,
16 following die bonding and wire bonding on a printed
17 circuit board substrate, the printing of liquid resin
18 takes place using a squeegee applied to the substrate
19 under vacuum. The substrate is then cured at a high
20 temperature to solidify the liquid resin. After curing,
21 solder balls for terminals are mounted on the backside
22 of the substrate. Conventional screen printing lacked a
23 process for removing the gas from the resin after the
24 printed after curing, causing cracking or warping
25 during the high temperature process.

26 In the method described by Okuno, a squeegee tool
27 applies conductive paste using a knife edge. In this
28 tool design, a vacuum is pulled inside the enclosure,

1 and paste is delivered, for illustrative example, by a
2 slot in the base of the tool.

3 An example of via filling using such a tool is shown in
4 Figs. 3A through Fig. 3F. In these figures, a vacuum
5 chamber 34 is evacuated by means of a vacuum pump (not
6 shown) connected to chamber 34 by a vacuum hose 36.
7 Once sufficient vacuum is created, a squeegee blade 38,
8 mounted on a moving member 39, moves across the surface
9 of a via containing wafer 40 from left to right in the
10 figure, held in a wafer holder or base plate 42,
11 delivering paste 44 at its leading edge. Paste 44 is
12 moved into position by a moving support 46 in a channel
13 or base plate slot 48 to which paste 44 is conducted by
14 a passageway (not shown). As shown in Fig. 3C, excess
15 paste is deposited over a movable support member 50 in
16 a channel or base plate slot 52. As shown in Fig. 3D,
17 support member 52 is moved upwards in channel 52, while
18 support member 46 is moved downwards in channel 48.
19 Additional paste is supplied to slot 52 through a
20 second passageway (not shown). As illustrated in Fig 3E
21 and Fig 3F, moving member 39 is then moved to cause
22 squeegee blade 38 to again traverse wafer 40, while
23 moving from right to left in the figure.

24 This method has a number of important shortcomings, the
25 most important of which is that there is not sufficient
26 constraint at the leading edge of the squeegee blade 38
27 to force the paste 44 to the bottom of a deep blind via
28 in a single, or often, even multiple passes. Whether

1 the paste 44 makes it to the via bottom is dependent on
2 a number of factors including the viscosity of the
3 paste 44 , the down force on the squeegee blade 38, the
4 quantity of paste 44 built up in front of the squeegee
5 blade 38, and the blade speed. With respect to the
6 down force, there is no method to fully contain the
7 paste 44 under pressure over a blind via except when
8 the squeegee blade 38 is passing directly overhead, and
9 even then paste 44 is free to smear out both in front
10 of and behind the blade 38. This makes multiple passes
11 a necessity. For high aspect ratio vias incomplete
12 filling can occur if the vacuum level is not
13 sufficiently low or if the paste 44 is of a very high
14 viscosity. The method is also not well suited to
15 semiconductor processing where substrates are round
16 rather than rectangular. In order to ensure complete
17 coverage of a round substrate, paste 44 must be pushed
18 repeatedly onto and off of the base plate 42 holding
19 the wafer. The linear motion of the squeegee blade 38
20 then leads to buildup at either end of the tool
21 necessitating some method of regular cleaning, and a
22 great waste of the conductive fill paste. Accordingly
23 there is a need to develop a more efficient method for
24 applying viscous conductive paste to semiconductor
25 wafers containing blind vias.

26 In United States Patent No. 5,244,143 to Ference et al.
27 as well as United States Patent No. 5,775,569 to Berger
28 et al., a tool and method for filling a mold with
29 molten solder are described. Since a mold is obviously

1 a rigid plate containing etched regions of specific
2 shapes, if these shapes take the form of cylinders then
3 the problem is essentially one of filling blind vias.
4 The filling head described in these patents is sealed
5 against the mold surface such that a vacuum can be
6 pulled in a region defined by a O-ring seal underneath
7 the head. Molten solder is then delivered through a
8 central slot in the head such that complete fill of the
9 evacuated solder mold cavities is achieved in a single
10 pass. An important distinguishing feature of this tool
11 and method is that it works well only for very low
12 viscosity materials such as molten solder which have a
13 viscosity on the order of 2 centipoise (for comparison
14 water is by definition 1 centipoise). The conductive
15 pastes used for semiconductor applications by contrast
16 have much higher viscosities ranging from 1,000
17 centipoise to greater than 50,000 centipoise and thus
18 require much higher internal pressures for them to be
19 effectively delivered to the wafer surface and into the
20 blind vias etched therein.

21 A via filling method using a pressurized paste nozzle
22 is described in United States Patent No. 6,506,332 to
23 J. L. Pedigo and it is clear that while this method has
24 advantages over the squeegee method described by Okuno,
25 it is primarily intended for use in organic printed
26 circuit board (PCB) high-density interconnect (HDI) and
27 sequential build up (SBU) laminate board type
28 applications. The apparatus described makes use of a
29 pressure head in combination comprising an O-ring

1 gasket which is held against the electronic substrate
2 to be filled and moved relative to that substrate such
3 that paste is forced into the via holes as the head
4 passes overhead. The apparatus as described has a
5 number of shortcomings which limit its applicability
6 for use with silicon wafer based packaging.
7 Specifically, the method does not employ vacuum which
8 is a practical necessity for complete filling of small,
9 high aspect ratio blind vias. Instead, the method is
10 described as a means of obtaining "reduced numbers of
11 air pockets formed in the via fill paste while
12 decreasing the amount of processing required per
13 board". Further, via sizes claimed range from 2 to 25
14 thousands of an inch (mils) in diameter, a span which
15 covers most important electronic wiring board
16 applications, but which neglects via features smaller
17 than 50 um (2 mils) in diameter which are easily
18 attainable in package substrates made from silicon
19 where blind vias may be on the order of 10 um in
20 diameter with aspect ratios greater than 10:1. Filling
21 such small blind features with viscous paste without
22 the aid of vacuum is highly problematic if not
23 impossible.

24 SUMMARY OF THE INVENTION

25 The present inventors have recognized that there is a
26 need for a method and tooling which employs a
27 combination of pressurized paste delivery in a vacuum
28 environment to enable the complete filling of etched

1 blind features, both lines and vias, in a silicon wafer
2 which may range in size from 10 um (< 0.5 mils) to 250
3 um (10 mils). Furthermore, there is a need for a
4 highly manufacturable process and tooling which is
5 easily adaptable for highly automated batch operation
6 compatible with CMOS back end of the line (BEOL)
7 processing.

8 It is therefore an aspect of the present invention to
9 provide a method for reliably filling vias with a
10 viscous substance.

11 It is another aspect of the present invention to
12 provide apparatus or tooling for reliably filling vias
13 with a viscous substance.

14 In accordance with the invention a method for filling
15 vias, and in particular blind vias, in a wafer,
16 comprises evacuating air from the vias; trapping at
17 least a portion of the wafer and a paste for filling
18 the vias between two surfaces; and pressurizing the
19 paste to fill the via. The method may further comprise
20 forming a seal between the surfaces so as to enclose
21 the portion of the wafer and the paste. The method may
22 further comprises moving the seal over successive
23 portions of the wafer to fill the vias.

24 Further, the method may comprise placing the paste on a
25 planar surface facing the wafer; and moving the planar
26 surface upon which the paste is placed into contact

1 with the wafer. The paste may be injected between one
2 of the surfaces and the wafer. Preferably, the paste
3 is injected between one of the surfaces and the wafer
4 after evacuating the air from the vias.

5 The method may further comprising providing an
6 evacuated space between the surfaces; and forcing the
7 surfaces together to force the paste into the vias. The
8 surfaces can forced together by atmospheric pressure.

9 Preferably, the paste is pressurized to greater than
10 atmospheric pressure, and more specifically to a
11 pressure in the range of 10 to 100 PSI.

12 In accordance with the invention, an apparatus for
13 filing vias in a wafer, comprises a chamber in which to
14 place the wafer, the chamber being capable of being
15 evacuated; a surface upon which to place the wafer; a
16 paste delivery portion for providing a paste to fill
17 the vias; and a paste filling portion for bringing the
18 paste into contact with the vias under pressure so that
19 the paste fills the vias. Preferably, the paste
20 filling portion provides the paste at a pressure with
21 the range of 10 to 100 PSI.

22 The paste delivery portion may comprise a surface onto
23 which the paste is deposited; and a mechanism for
24 applying pressure so that the paste on the surface is
25 forced into contact with the wafer. The paste delivery
26 portion may also comprise a surface onto which the

1 paste is deposited; and a passageway through which the
2 paste is delivered to the surface. The mechanism for
3 applying pressure may comprise a plate which defines
4 the surface; and components for applying a pressure
5 differential to the plate so as to force the plate
6 toward the wafer. A compliant material may be disposed
7 on the surface to which the paste is applied.

8 The paste filling portion may comprise a plate having a
9 portion for receiving the paste; a first seal for
10 sealing the plate to the surface upon which the wafer
11 is placed; a second seal for sealing the paste between
12 the plate and the plate and the wafer; and a mechanism
13 for forcing the plate towards the wafer so that the
14 paste is forced into the vias of the wafer.

15 The mechanism for forcing the plate towards the wafer
16 may comprise a gas removal apparatus for evacuating gas
17 between the plate and the surface upon which the wafer
18 is placed; and gas replacement apparatus for replacing
19 gas evacuated from the chamber. The gas replacement
20 apparatus may comprise an opening through which gas is
21 permitted to enter the chamber.

22 The surface upon which to place the wafer may comprise
23 a base plate having a recess for the wafer or it may be
24 a surface of an electrostatic chuck.

25 The paste delivery portion may comprise a pressurized
26 paste reservoir.

1 Also in accordance with the invention, the paste
2 filling portion may comprise a piston housing having an
3 opening for receiving a piston; a compliant seal for
4 sealing the piston housing to a portion of the wafer so
5 as to confine the paste; a piston disposed in the
6 piston housing; and a piston actuator for forcing the
7 piston toward the wafer; wherein the paste delivery
8 portion provides the paste to the opening.

9 The apparatus in accordance with the invention may
10 further comprise a mechanism for moving the piston
11 housing so that the seal is compressed for filing the
12 vias. The mechanism for moving the piston housing may
13 further move the piston housing to a position wherein
14 the seal is compressed to a lesser degree than when the
15 vias are filled, to thereby allow the piston housing to
16 be moved so that the piston housing is disposed so as
17 to be in a position to fill vias of one or more
18 successive portions of the wafer with paste delivered
19 to the opening.

20 The apparatus may further comprise a mechanism for
21 cleaning the piston of excess paste after vias of a
22 wafer have been filled.

23 The paste filling portion of the apparatus may comprise
24 an elongate member having a surface with a slot through
25 which paste is provided to the wafer; and a compliant
26 seal for sealing the surface to the wafer.

1 In accordance with the invention, the apparatus may
2 further comprise a mechanism for translating the member
3 and the wafer with respect to one another so as to fill
4 vias in successive portions of the wafer and a
5 mechanism for rotating the member and the wafer with
6 respect to one another so as to fill vias in successive
7 portions of the wafer. The mechanism for rotating the
8 member and the wafer with respect to one another may
9 comprise a rotating base having the surface upon which
10 the wafer is placed.

11 The apparatus may be configured to accept a circular
12 wafer, wherein the elongate member is disposed radially
13 with respect to the wafer. Preferably, the elongate
14 member has a length less than that a radius of the
15 wafer, and the further comprises a mechanism for
16 rotating the wafer; and a mechanism for radially
17 translating the member in a radial direction with
18 respect to the wafer. The mechanism for rotating the
19 wafer may include a rotation speed control to control
20 speed of rotation of the wafer. The mechanism for
21 radially translating the member may include a
22 translation speed control to control speed of
23 translation of the member with respect to the wafer.

24 The mechanism for radially translating the member may
25 include a worm gear assembly, and a motor for rotating
26 a drive shaft of the assembly.

1 BRIEF DESCRIPTION OF THE DRAWINGS

2 These and other aspects, features, and advantages of
3 the present invention will become apparent upon further
4 consideration of the following detailed description of
5 the invention when read in conjunction with the drawing
6 figures, in which:

7 Fig. 1A to Fig. 1F illustrate, in cross sections, the
8 stages of a prior art process flow for creating a
9 silicon-based chip carrier complete with conductive
10 through vias, topside landing joins or bumps and
11 backside solder connections.

12 Fig. 2 illustrates prior art silicon based carrier
13 populated with chips mounted on a first (ceramic
14 module) and second (PCB) level package.

15 Fig. 3A illustrates a prior art system using paste
16 delivery through a base plate slot with a vacuum
17 squeegee blade at a home position.

18 Fig. 3B illustrates the system of Fig. 3A with the
19 vacuum squeegee blade at a midway position during a
20 first pass paste filling.

21 Fig. 3C illustrates the system of Fig. 3A with the
22 vacuum squeegee blade at a terminal position after a
23 single pass.

1 Fig. 3D illustrates the system of Fig. 3A with paste
2 delivery through a base plate slot with the vacuum
3 squeegee blade at terminal position.

4 Fig. 3E illustrates the system of Fig. 3A with the
5 vacuum squeegee blade at a midway position during a
6 second (return) pass paste filling.

7 Fig. 3F illustrates the system of Fig. 3A with the
8 vacuum squeegee blade at a home position after one
9 complete cycle including two passes across the surface
10 of a wafer.

11 Fig. 4A illustrates an apparatus in accordance with the
12 invention with a vacuum piston tool having an upper
13 surface coated with paste, in an initial position.

14 Fig. 4B illustrates the apparatus of Fig. 4A in a
15 configuration wherein an inner vacuum port of the is
16 held open while an outer vacuum port back fills to
17 atmosphere.

18 Fig. 4C illustrates the apparatus of Fig. 4A in a
19 configuration wherein the inner port is set to back
20 fill to atmosphere so that a paste is in the vias of
21 the wafer and an overburden is on the wafer surface.

22 Fig. 5A is a cross-sectional view of an apparatus in
23 accordance with a second embodiment of the invention

1 wherein a compact piston head is in a starting position
2 on the surface of a wafer.

3 Fig. 5B is a cross-sectional view of the apparatus of
4 Fig. 5A wherein the compact piston head is moved so as
5 to compress a gasket against the wafer.

6 Fig. 5C is a cross-sectional view of the apparatus of
7 Fig. 5A wherein paste is dispensed into an evacuated
8 region between the piston face and the wafer surface.

9 Fig. 5D is a cross-sectional view of the apparatus of
10 Fig. 5A wherein the piston extends downward compressing
11 paste into blind vias of the wafer.

12 Fig. 5E is a cross-sectional view of the apparatus of
13 Fig. 5A wherein the piston is withdrawn and the piston
14 head is in a position resulting in light pressure
15 between the gasket and the surface of the wafer.

16 Fig. 5F is a cross-sectional view of the apparatus of
17 Fig. 5A wherein the piston head is in a second
18 location, while maintaining a light contact force
19 between the gasket and the surface of the wafer.

20 Fig. 5G is a side elevational view of the piston head
21 apparatus of Fig. 5A wherein the piston is at location
22 away from the wafer surface and extends to contact
23 apparatus for removing excess paste.

1 Fig. 6A is a partial bottom view of an apparatus in
2 accordance with a third embodiment of the invention.

3 Fig. 6B cross-sectional side elevational view of the
4 apparatus of Fig. 6A.

5 Fig. 7 is a cross-sectional view a vacuum paste nozzle
6 dispense chamber, utilizing the apparatus of Fig. 6A
7 and Fig. 6B.

8 Fig. 8 is a plan view of a linear nozzle dispense
9 operation inside of a vacuum environment, utilizing the
10 apparatus of Fig. 6A and Fig. 6B.

11 Fig. 9A, Fig. 9B and Fig. 9C are plan views of rotary
12 nozzle dispense operations inside of a vacuum
13 environment, utilizing an apparatus in accordance with
14 Fig. 6A and Fig. 6B.

15 DESCRIPTION OF THE INVENTION

16 Variations described for the present invention can
17 be realized in any combination desirable for each
18 particular application. Thus particular limitations,
19 and/or embodiment enhancements described herein, which
20 may have particular advantages to the particular
21 application need not be used for all applications.
22 Also, it should be realized that not all limitations
23 need be implemented in methods, systems and/or

1 apparatus including one or more concepts of the present
2 invention.

3 Referring to Fig. 4A, in a first apparatus and method
4 in accordance with the invention, an outer processing
5 chamber 60 has an outer vacuum port 62 to which a
6 vacuum source (not shown) is connected. Chamber 60 is
7 evacuated, as represented by arrow 65, through port 62.
8 Conductive paste 64 is applied to a portion of one face
9 of a top plate or piston 66, which is coated with
10 Teflon or another nonstick and compliant surface
11 material 68.

12 As used herein, the term paste refers to any material,
13 and especially to electrically conductive materials,
14 having a viscosity within a broad range, including a
15 range spanning that of traditional pastes, such as
16 highly loaded metal or metal-dielectric filled pastes
17 used in screen printing of printed circuit boards,
18 aqueous suspensions containing fine grains of
19 conducting material, and organo-metallic liquids.

20
21 An inner O-ring 69 surrounds the surface material and
22 the paste 64. The wafer 70 being processed is held on
23 the face of a bottom or base plate 72 by means of a
24 countersunk recess or banking pins (not shown). The
25 planar surfaces of piston 66 and base plate 72 are held
26 apart by a compliant outer O-ring 74. Air in the
27 gap separating the paste-coated side from the wafer, is
28 prevented from being trapped in the vias under the

1 paste by achieving a sufficient vacuum in the space 75
2 between piston 66 and base plate 72. This is
3 accomplished by evacuating space 75 by means of a
4 passageway 76 in piston 66, which is connected to a
5 vacuum hose 78, that is in turn evacuated by a vacuum
6 system (not shown) connected to an inner vacuum port
7 80. Thus, in Fig. 4A, the inner vacuum port 80 and the
8 outer vacuum port 62 are both open so that the space 75
9 between the paste 64 and the wafer 70 is evacuated
10 without collapse of the plates toward one another.

11 Pressure is then applied to the piston 66, bringing the
12 paste into contact with the wafer 70. As shown in Fig.
13 4B this pressure, represented by arrows 82 is easily
14 achieved by maintaining vacuum inside the piston
15 enclosure defining space 75, while back filling the
16 outer chamber 60 with air, for example, at atmospheric
17 pressure, as represented by arrow 65A. The inner
18 O-ring 69 forms a baffle enclosure, preventing the
19 paste from escaping at the edge of the wafer 70 and
20 assuring that sufficient pressure is available to force
21 the paste into the evacuated vias of wafer 70. Once
22 the vacuum is released from the inner piston, by
23 releasing the vacuum at inner vacuum port 80, and
24 allowing space 75 to revert to, for example,
25 atmospheric pressure, with arrow 80A representing the
26 flow of air, outer O-ring 74 provides a restoring force
27 which increases the separation between piston 66 and
28 base plate 72, as shown in Fig. 4C.

1 Several additional features are available for the
2 apparatus illustrated in Fig 4A to Fig. 4C. In the
3 case of a lower viscosity liquid paste, as shown in
4 Fig. 4B, delivery may be achieved via an orifice 84 in
5 the piston 66 and surface material 68 after the vessel
6 is evacuated. In this case a precise amount of paste
7 is delivered, through a preferably flexible paste
8 delivery tube 86 (which may penetrate chamber 60 in an
9 airtight manner) and allowed to flow across the wafer
10 surface and into the evacuated vias before final
11 pressure is applied. In an alternate embodiment, the
12 wafer mounting surface and paste-covered surface are
13 inverted. In this case, the automatic dispensing of
14 the paste takes place through an orifice in the lower
15 plate, and a lower-viscosity paste is allowed to pool
16 for a precise time before the wafer is brought into
17 contact and pressure applied. This may be visualized
18 by inverting Fig. 4B. In this embodiment, paste
19 overburden must be removed in a subsequent step by any
20 number of methods including but not limited to a
21 squeegee or doctor blade as described above, or a
22 rotary brush cleaning method.

23 Referring to Fig. 5A to Fig. 5F, in the second
24 embodiment of the invention, a compact piston 90 is
25 disposed in a piston housing 91, of a movable, compact,
26 operating piston head 92. Piston head 92 is disposed
27 inside a vacuum chamber 94. Provision is made to move
28 the compact piston head 92 in steps across the surface
29 of a wafer 96 held in, for example, an electrostatic

1 chuck 98. The filling begins once the chamber 94 is
2 fully evacuated. As illustrated in Fig. 5B, the piston
3 head 92 is moved to an appropriate starting point (Fig.
4 5a) and the piston housing 91 is pushed vertically
5 against the wafer surface, by for example, vertical
6 expansion of an actuator 99, to compress an O-ring
7 gasket 100. As illustrated in Fig. 5C, paste, stored
8 in a pressurized paste feed and reservoir 102 is
9 dispensed into the evacuated space 108 underneath the
10 compact piston through a paste feed tube or hose 104
11 terminating in an opening 106 in the space 108 under
12 piston 90 and above wafer 96.

13 As illustrated in Fig. 5D, the piston 90 is then
14 actuated by a piston drive mechanism 110, which forces
15 piston 90 downward, thus compressing the paste into the
16 vias of wafer 96 below. Piston drive mechanism 110 may
17 be operated in any of several conventional ways, such
18 as by means of an electric motor or a pneumatic or
19 hydraulic drive. Drive mechanism 110 may then be
20 reversed so that piston 90 withdraws. The downward
21 force of the piston housing 91 of head 92 is released
22 by actuator 99, so that O-ring gasket 100 decompresses
23 but remains lightly in contact with the upper surface
24 of wafer 96. As illustrated in Fig. 5F, the entire
25 head 92 is translated across the surface of the wafer
26 96 to the next delivery location and the process
27 described above is repeated. This may be done at
28 successive locations until vias in the entire wafer
29 accessible by the head are filled. This method is

1 advantageous in that it becomes quite easy to deliver
2 the paste directly to the point of use. Further, as
3 illustrated in Fig 5G, it is relatively simple to
4 include a cleaning station, comprising, for example, a
5 rotating cleaning wheel 112, located away from the
6 wafer chuck 98, to remove excess paste from the bottom
7 of the compact piston face before subsequent filling.
8 To perform this operation, head 92 is moved to a
9 position removed from chuck 98, and piston drive
10 mechanism 110 moves piston 90 so that its lower surface
11 extends outside of piston housing 91 and below O-ring
12 gasket 100.

13 It is noted that face of piston 90 face may be
14 circular, it is advantageous for it to be a square or
15 rectangular in the case of a x-y translation system.
16 In the case of a rotational system where the head is
17 fixed and the wafer rotates, it is advantageous for the
18 head to assume a shape equal to some reasonable segment
19 of a circle.

20
21 Referring to Fig. 6A (a partial bottom view), Fig. 6B
22 (a cross-sectional view) and Fig. 7, a cross sectional
23 view), in a third embodiment of the invention, paste is
24 applied using a pressurized nozzle 120, having an
25 O-ring seal or gasket 121 held firmly in contact with
26 the upper surface of a wafer 122. Wafer 122 is
27 supported in a countersunk notch or recess 124 of a
28 base plate 126 inside a vacuum environment, such as a
29 vacuum chamber 128. Conductive paste 129 is applied

1 through a slot 131. In Fig. 7, nozzle 120 is shown
2 moving across wafer 122 in the direction of arrow 130.
3 As with the first and second embodiment, no filling
4 occurs until the entire chamber 128 has been pumped
5 down to a vacuum level of less than 10 Torr, and
6 preferably closer to 1 Torr. Conductive paste, under
7 pressure, is supplied to nozzle 120 via a delivery tube
8 132 connected to a paste reservoir 134, which supplies
9 paste upon movement of a piston assembly 135. An
10 advantage of this embodiment is that the pressurized
11 paste cartridge supplying the paste to the nozzle via
12 the delivery tube is disposed inside the vacuum chamber
13 and may be electronically or mechanically actuated
14 therein. In this configuration there is no possibility
15 of air seeping into the paste delivery system, and
16 provision is made for preventing air from slowly
17 permeating the paste itself, which is of critical
18 importance for pastes which have been purposefully
19 mixed and dispensed under vacuum specifically for this
20 application.

21 Referring also to the linear scanning operation shown
22 in Fig. 8, the nozzle 120 begins at a position to the
23 left of the wafer 122 held in countersunk recess 124 of
24 base plate 126 (Fig. 7), and travels as indicated by
25 arrow 127. It is preferable that recess 124 either
26 match, or be slightly less deep than, the full
27 thickness of wafer 122 to ensure that the upper surface
28 of wafer 122 is either on grade, or slightly higher (~
29 1 mil) than, the surface of the base plate over which

1 nozzle 120 moves. This ensures that the compliant
2 nozzle O-ring gasket 121 will remain in compressed
3 contact against the upper surface of wafer 122
4 throughout the filling operation. As described, for a
5 paste of a given viscosity the controllable filling
6 parameters are vacuum level inside the chamber 128,
7 pressure applied to the paste inside the nozzle 120,
8 and scanning speed of nozzle 120 over the surface of
9 wafer 122.

10 It is noted that with the exception of the rotary
11 embodiments shown in Figs. 9A, 9B and 9C, below the
12 wafer fits snugly into a machined, countersunk notch in
13 the tool base plate so that the wafer surface is very
14 nearly planar with respect to the base plate surface.
15 The nozzle moves across the surface filling the
16 evacuated vias in its path and leaving only a very thin
17 overburden on the wafer surface. Alternatively,
18 positioning or banking pins may be used to hold the
19 wafer in place.

20 As shown in Figs. 9A and 9B, the pressurized paste
21 nozzle may also be advantageously applied in a rotary
22 configuration wherein the wafer is held on a rotating
23 base plate (not shown in Figs. 9A to 9C) by, for
24 example an electrostatic chuck (also not shown). The
25 wafer 122A, 122B, 122C rotates as represented by arrow
26 125. The electrostatic chuck may be of conventional
27 design with respect to the manner in which the wafer is
28 held, but may differ in that provisions are made for

1 applying the voltage used to secure the wafer with
2 electrical connection means that permit rotation of the
3 base plate.

4 A nozzle 120A is held stationary in a radial direction
5 with respect to a rotating wafer 122A to apply paste
6 123A. This method has the advantage that the nozzle
7 never touches another surface except that of the wafer
8 to be filled. The nozzle may be designed to be less
9 wide than the wafer radius to provide an edge exclusion
10 zone where no paste is applied. Both of these features
11 serve to make this embodiment of the invention
12 particularly compatible with typical CMOS semiconductor
13 processing.

14 The wafer is fixed on a rotating chuck (for example, an
15 electrostatic chuck, as described above) and the paste
16 nozzle is brought into contact with the wafer and moves
17 across the surface filling the evacuated vias in its
18 path and leaving a very thin overburden of the paste
19 123A on the surface of wafer 122A. As shown in Fig.
20 9A, a fixed nozzle can have a slot dimension nearly
21 equal to the wafer radius as shown, or the full
22 diameter.

23 Fig. 9B illustrates an embodiment that is particularly
24 preferred, where the nozzle 120B, and thus the slot
25 dimension, is less than the radius of the wafer 122B.
26 In this embodiment the nozzle 120B must be moved, for
27 example, in equal steps along the radial direction,

1 such that separate paste delivery tracks 140A, 140B,
2 140C, etc. are defined. An exemplary mechanism for
3 providing such movement is described below with respect
4 to Fig. 9C. The combination of vacuum, paste pressure
5 and dwell time of the nozzle over a via or collection
6 of vias are important filling parameters. The
7 embodiment shown in Fig. 9B allows wafer rotation speed
8 to be adjusted for each separate paste delivery track
9 to ensure that the average dwell time of the nozzle in
10 any given location is approximately equal across the
11 wafer. Another advantage of the smaller nozzle is that
12 a higher overall paste pressure can be developed for a
13 given amount of nozzle down force. The pressure of the
14 paste multiplied by the area defined by the slot O-ring
15 yields the force with which the nozzle must be held
16 against the wafer surface to avoid any leakage under
17 the O-ring seal. In general, any moving mechanical
18 system such as that shown in Fig. 9B will have a
19 maximum structural force at which it can properly
20 operate. If the paste delivery area defined by the
21 nozzle is reduced, the same mechanical down force will
22 allow a higher nozzle pressure to be developed before
23 the paste leakage condition is met.

24 Referring to Fig. 9C nozzle 120C is supported on an arm
25 142 connected to a block 144 with a threaded hole 145.
26 A worm gear drive assembly comprises a threaded shaft
27 146, supported in fixed bearing blocks 148 and 150,
28 extends through and engages the threads of hole 145.
29 Shaft 146 is rotated by a motor 152 controlled by a

1 speed controller 154. Motion of block 144 resulting
2 from rotation of shaft 146 causes nozzle 120C to move
3 radially with respect to wafer 122C. It will be
4 recognized that in addition to depositing separate
5 paste delivery tracks 140A, 140B, 140C, etc., as
6 described above with respect to Fig. 9B., it is
7 possible, once paste delivery track 140A has been
8 deposited, to continuously move nozzle 120C radially
9 outward with respect to wafer 122C until a desired
10 surface region has been covered with paste. Suitable
11 continuous adjustment in the rotational speed of the
12 wafer is made to assure reasonably uniform paste
13 delivery, as described.

14 It is noted that the worm gear drive mechanism
15 described above with reference to Fig. 9C is merely
16 exemplary, and that any other suitable drive mechanism
17 may be used. Further, any such drive mechanisms may be
18 used in any embodiment of the invention described in
19 the various figures, wherein translational motion is
20 required.

21 The three general embodiments outlined describe only
22 the paste application step itself. A production tool
23 based on any of these preferably also comprise the
24 following functions: automated wafer handling from/to a
25 cassette to the paste apply stage (loadlock); provision
26 for cleaning the edge (if necessary) of the wafer
27 (similar to edge bead removal in a resist coater);
28 automated paste pressure control, metering and

1 dispense; some form of automated inspection; and
2 automated loading into a batch vacuum oven for low
3 temperature drying *in-situ*.

4 The invention described herein has particular
5 application to a semiconductor or glass substrate-based
6 carrier for mounting and packaging multiple integrated
7 circuit chips and/or other devices. The carrier is a
8 freestanding chip or wafer with insulated, conductive
9 through-vias exposed on its top and underside, to
10 connect flip-chip and other device I/O through the
11 carrier to next-level packaging, board, or other
12 flip-chips mounted on the bottom side. However, it may
13 be applied to any situation wherein a via, and in
14 particular a deep via, must be filled with a viscous
15 substance such as a paste.

16 Thus, it is noted that the foregoing has outlined some
17 of the more pertinent objects and embodiments of the
18 present invention. The concepts of this invention may
19 be used for many applications. Thus, although the
20 description is made for particular arrangements and
21 methods, the intent and concept of the invention is
22 suitable and applicable to other arrangements and
23 applications. It will be clear to those skilled in the
24 art that other modifications to the disclosed
25 embodiments can be effected without departing from the
26 spirit and scope of the invention. The described
27 embodiments ought to be construed to be merely
28 illustrative of some of the more prominent features and
29 applications of the invention. Other beneficial results

1 can be realized by applying the disclosed invention in
2 a different manner or modifying the invention in ways
3 known to those familiar with the art. Thus, it should
4 be understood that the embodiments has been provided as
5 an example and not as a limitation. The scope of the
6 invention is defined by the appended claims.